# THE INFLUENCE OF SOIL FACTORS ON DISEASE RESISTANCE.

By ALBERT HOWARD, C.I.E.

*Imperial Economic Botanist, Pusa, India.*

(With 5 Text-figures.)

## I. Introduction.

One of the features of the modern literature on agricultural science is the number of papers dealing with the diseases of plants in which insects and fungi are concerned. Much less attention, however, has been paid to disease and to the factors on which disease-resistance depends. It is now well understood that the unit species which go to make up the varieties of cultivated crops differ greatly among themselves in resistance to certain parasites and that in some cases at any rate this character can be inherited. Further, it is a matter of common experience that the various diseases only become epidemic where conditions assist the spread of the parasite and at the same time injuriously affect the condition of the crop which is being attacked. Briefly stated, the ravages of any parasite are found to depend on the kind of plant grown and on the conditions under which it is cultivated. We know practically nothing however of the reasons why one unit species is resistant to disease and why others, belonging to the same variety, do not possess this character to any great degree. Further, little has been done to trace the influence of separate soil factors on disease-resistance.

During the last 15 years, opportunities of growing the same crop in India under widely different conditions of soil and climate and of studying the distribution of the crops of this continent have been utilised. At the same time, many observations on the incidence of disease have been made and of the general conditions which appear to precede serious damage by parasites. In some instances, the matter has been carried further and an attempt has been made to ascertain what soil factors are responsible in lowering the natural resistance of a crop to attack. In practically every case, light has been thrown on the subject by a systematic examination of the root-system[1]. The results obtained are summed up in the present paper. They are admittedly incomplete but are put forward with a definite purpose, namely, to suggest that much more attention should be paid in future investigations of diseases to the general facts of root-development and to the condition of the absorptive areas of the root-system both before the actual advent of the parasite and during the period when the disease is actually established. Up to the present, attention has been paid chiefly to the influence of soil-aeration and soil temperature on disease-resistance.

## II. Soil-Aeration.

The importance of the soil-aeration factor in the growth of crops has been obscured by several causes. In the first place, the chief agricultural experiment stations at which soil problems have been studied have been situated in humid regions where the soil obtains frequent applications of highly oxygenated water in the form of rainfall. In the second place, the discovery of artificial manures has influenced agricultural science just as profoundly as it has revolutionised practice. When most soils are found to respond at once to applications of combined nitrogen, phosphates and potash or of various combinations of these substances and when artificial manures are purchasable in any market place of the country, it is natural to regard such soil deficiencies as due to exhaustion and to find in applications of artificial manures the natural remedy. Under circumstances such as these no stimulus to the study of factors like soil-aeration is likely to occur. When, however, we push over cultivation into the desert and endeavour to make up for defective rainfall by irrigation which often produces impermeable crusts on the surface, the importance of soil-aeration soon becomes manifest[2]. Deprived of regular applications of dissolved oxygen in the form of rainfall, the crop and the soil have to rely on other means of obtaining new supplies of this gas and of getting rid of accumulations of carbon dioxide. Under such circumstances the physical condition of the soil takes on a new meaning and any cause which affects gaseous interchange between the pore spaces and the atmosphere is found to affect the crop immediately. Not only does soil-aeration influence the amount of growth but also the development of the root-system and the resistance of the crop to disease. In some cases defective soil-aeration actually causes disease.

[1] *Agr. Jour. of India*, Special Indian Science Congress Number, 1917, p. 17.

[2] *Bulletins* 52–61, Agr. Research Institute, Pusa, 1915–16.

*The wilt-disease of Java indigo and other monsoon crops.* These wilt-diseases are examples of a definite disease in which parasites have not yet been shown to play a part.

Java indigo (*Indigofera arrecta* Hochst.), the species now generally cultivated in Bihar, frequently suffers from wilt during the late rains. At the beginning of the monsoon, growth is normal but in wet years a change takes place about mid-July in the character of the foliage while the rate of growth slows down. The leaves alter in appearance, assume a yellowish-green, slaty colour, become reduced in size and show extensive longitudinal folding. After this, leaf fall is rapid until only stunted tufts of foliage at the ends of the branches remain. In severe cases, this is followed by the death of the plant, the process taking place slowly, a branch at a time. The external symptoms of wilt suggest extensive root damage which is confirmed by exposing the root-system by means of a Knapsack sprayer. Wilted plants are found to possess very few fine roots and nodules in an active condition. The main tap-root and the laterals are alive and normal but the fine roots are mostly dead or discoloured and the number of absorbing root hairs is exceedingly small. The destruction of the active root-system including the nodules takes place from below upwards. When wilt is well established, the absorbing roots still alive are all in the upper two or three inches of soil. Evidently some factor is in operation which destroys the fine roots in the subsoil and which afterwards affects those towards the surface.

Other investigators have failed to find any parasite responsible for the trouble. No insects could be discovered attacking the fine roots and none of the well-marked appearances of fungoid attack were evident.

The association of extensive root damage with wilt suggested a detailed study of the roots. For this purpose, it was necessary to expose the root-system without damage including the absorbing areas and the nodules. This is easily accomplished in the fine silt-like soils of Bihar by means of a Knapsack sprayer. The range in the root-systems of the various types which make up the indigo crop was found to be as great as that of the above-ground portion of the plant. The mode of branching of the roots closely corresponded with that of the shoot. The type of rooting could always therefore be foretold from the mode of branching. The root-system in this crop is the mirror image of the shoot. Nodular development was found to be most intense at the break of the rains in May and June and to be most pronounced on the roots near the surface. Soil-temperature was found to affect the growth of roots and a distinct resting period ensued during the cold weather of December, January and early February. Of great interest were the results obtained when actively growing indigo plants were cut back. This was followed in all cases by the death of the fine roots and nodules and before new shoots were formed extensive root regeneration was necessary. The formation of new roots during the monsoon was found to be more rapid if there was a break in the rains after cutting back, and to take place much more readily in the case of surface rooted types than if the root-system was deep. The next step in the investigation was to determine whether wilt is actually caused by the gradual destruction of the fine roots and nodules as seemed probable. Wilt was produced experimentally in the following ways:

(*a*) By the mutilation of the root-system. One example of wilt produced in this manner may be quoted. An indigo plant was partially cut back on June 21st, 1919. On August 5th, the roots were exposed by the Knapsack sprayer and were found normal and healthy in all respects. Before replacing the soil, the fine roots and nodules on the laterals were removed to the depth of one foot but below this point the soil was not disturbed. Wilt rapidly developed and when the entire root-system was again exposed on August 29th very few active roots were found.

(*b*) By deep interculture, during the rains, of indigo sown in lines. Two well-marked cases of this have occurred at Pusa recently. In 1918, Java indigo, sown in double lines with wide spaces between to admit of interculture, speedily lost in vigour and developed much more wilt than the broadcast crop side by side which was not cultivated. In 1919, the experiment was repeated with four types of indigo sown on two different types of soil. The indigo grown in double lines with interculture yielded less crop and developed more wilt than the neighbouring broadcast plots which were not cultivated. The cultivation was found to destroy the lateral roots near the surface on which the plants were dependent at that period of the year.

(*c*) By October and November cultivation of old indigo, dependent for its crude sap on superficial roots. After the rains, the only active roots of an old indigo crop are quite close to the surface. If the land is cultivated these are destroyed and wilt develops. Mulching the surface with straw to preserve the moisture and to prevent these roots drying up as the season changes has the reverse effect.

(*d*) By cutting back young rapidly growing August-sown plants in October, when the reserve materials in the tap-root are insufficient for root regeneration. Cutting back at this period kills the majority of the plants but a few produce wilted shoots.

(*e*) By complete cutting back in the cold weather when the root regeneration of surface-rooted types is difficult probably on account of low soil temperatures. In December, 1918, 641 healthy well-developed August-sown plants were cut back when over five feet high. The following February, 162 of these were badly wilted, 185 were partly wilted and 294 were normal. A number of root washings were made and in all cases wilt was found to be associated with the practical absence of root regeneration. The plants which developed wilt were those which had their laterals near the surface, the deeper rooted plants producing normal growth. Thus the monsoon results are reversed during the cold weather. In the cold season, the factor which checks root regeneration is apparently low soil-temperature. This affects surface-rooted plants much more than deep-rooted types. The plants were kept under observation till April by which time a remarkable change had taken place. The rise in the soil-temperature in March caused the wilted plants to recover, root regeneration took place and the growth became normal.

(*f*) By waterlogging slowly from below during the rains, by closing the drainage openings of lysimeters. At the beginning of the rains of 1918, indigo was sown in two sets of lysimeters. These were air-tight cemented tanks, 1/1000 of an acre in area, four feet high, built above the ground level and provided with drainage openings which could be closed at will. In one set, alluvial soil exceedingly rich in available phosphate (0·318 per cent.) from the Kalianpur Farm near Cawnpore was used, in the other light Pusa soil was employed. The latter, when analysed by Dyer's method, gives very low figures for available phosphate (0·001 per cent.). In both soils the indigo in the lysimeters with free drainage escaped wilt altogether. When the drainage openings were closed and waterlogging from below took place all the plants were wilted in both Kalianpur and Pusa soil. Wilt in the Kalianpur soil (rich in available phosphate) was much worse than in Pusa soil (low in available phosphate). The growth in Kalianpur soil was much slower than in Pusa soil.

These experiments establish the cause of wilt. The disease results from damage to the fine roots and nodules under circumstances where root regeneration is difficult or impossible.

As has been stated above wilt generally makes its appearance during the latter half of the rainy season. During this period it is often the cause of low yields of indigo. The agency which brings about wilt during this period has been found to be defective soil-aeration caused by the upward rise of the ground water, combined with the destruction of the porosity of the surface soil by heavy rain. This interferes with soil-aeration and produces root asphyxiation. Soon after the monsoon begins in June, the level of the rivers rise followed by that of the ground water. The movements of the river levels and the general ground water are illustrated by the curves shown in Fig. 1, which represent the state of affairs of the river at Pusa and of one of the wells (about a quarter of a mile distant) for the years 1910 and 1912.

The curves are typical of the subsoil water conditions of North Bihar

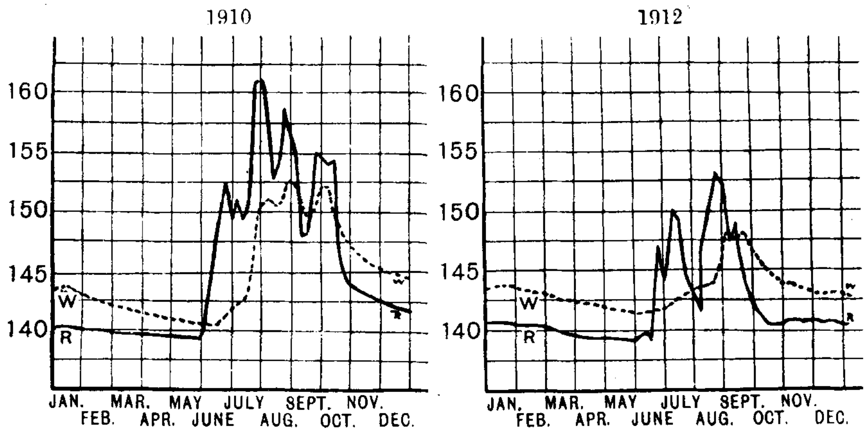


Fig. 1. Changes in the river and well levels at Pusa. The well levels are shown by dotted lines. The observations are expressed in feet above mean sea-level.

Table I. *Percentage of $CO_2$ in the Soil Gas from three different plots in the Botanical Area, Pusa, in* 1919[1].

| Month and date when the soil gas was aspirated and analysed | Plot No. 1, grassed down | Plot No. 2, grassed down but partially aerated by trenches | Plot No. 3, surface cultivated | Rainfall in inches since Jan. 1st, 1919 |
|---|---|---|---|---|
| Jan. 13th, 14th and 17th | 0·444 | 0·312 | 0·269 | Nil |
| Feb. 20th and 21st | 0·472 | 0·320 | 0·253 | 1·30 |
| March 21st and 22nd | 0·427 | 0·223 | 0·197 | 1·33 |
| Apr. 23rd and 24th | 0·454 | 0·262 | 0·203 | 2·69 |
| May 16th and 17th | 0·271 | 0·257 | 0·133 | 3·26 |
| June 17th and 18th | 0·341 | 0·274 | 0·249 | 4·53 |
| July 17th and 18th | 1·540 | 1·090 | 0·304 | 14·61 |
| Aug. 25th and 26th | 1·590 | 0·836 | 0·401 | 23·29 |
| Sept. 19th and 20th | 1·908 | 0·931 | 0·450 | 30·67 |
| Oct. 21st and 22nd | 1·297 | 0·602 | 0·365 | 32·90 |
| Nov. 14th and 15th | 0·853 | 0·456 | 0·261 | 32·90 |

[1] I am indebted to Mr Jatindranath Mukherji for these determinations.

during the rain. That the rise of the subsoil water combined with the consolidation of the surface soil does interfere with soil-aeration is shown by the periodic determination of the soil gases at Pusa during 1919 (Table I), a year when rainfall was below the average and when the movements of the ground water were very slight.

During this year, indigo wilt was almost negligible and only made

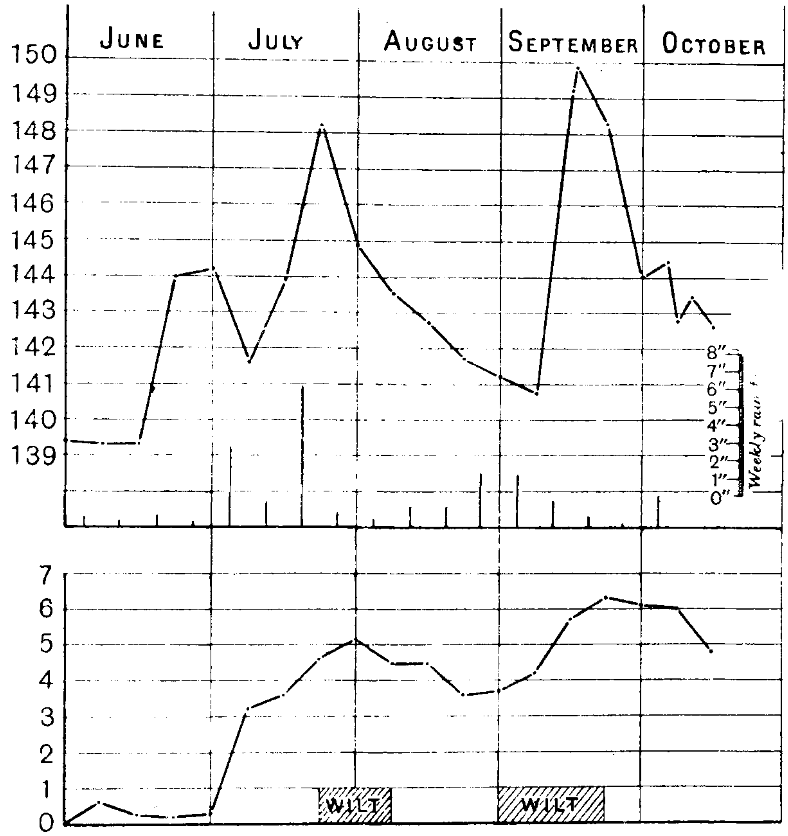


Fig. 2. Rise and fall of the river and well levels at Pusa in 1919.

its appearance at Pusa on two occasions, between July 23rd and Aug. 7th, and again between Sept. 1st and 23rd. A reference to Fig. 2 will show that these attacks followed a rise of the ground water combined with heavy rain. During these periods, the roots of many of the affected plants were exposed and compared with those of normal individuals. In all cases, most of the nodules and fine roots of the wilted plants were dead except a very few near the surface of the ground. The root tips of normal plants exhibited marked aerotropism and were found to have turned upward towards the air. This continued until a break in the rains and a fall of the ground water restored soil-aeration when normal growth ensued.

Confirmatory evidence of the view that wilt during the rains is due to the destruction of the fine roots and nodules caused by poor soil-aeration has been obtained in several directions. The actual soil conditions under which wilt naturally occurs can be reproduced in a lysimeter by closing the drainage openings. The slow rise of the water-table leads to the destruction of the fine roots and nodules from below upwards and to the production of wilt. Recovery from monsoon wilt takes place in

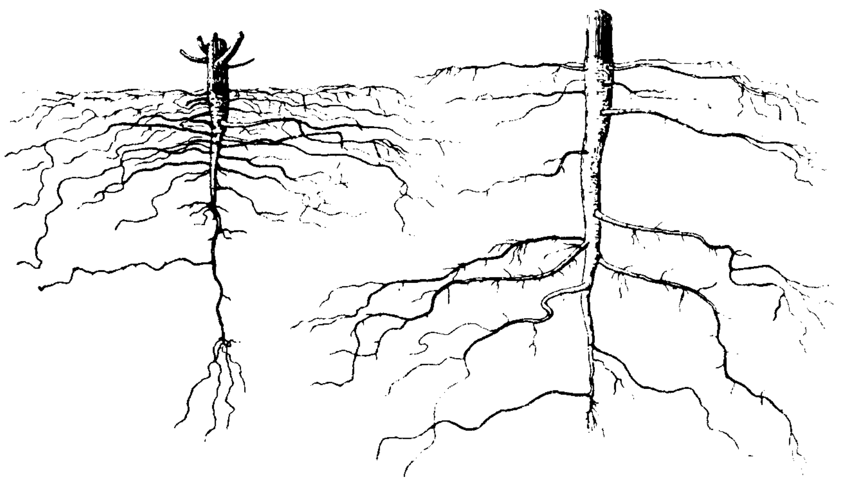

Fig. 3. The root-system of *Hibiscus Sabdariffa* (left) and *H. cannabinus* (right).

the lysimeters and also in the field after the aeration of the soil improves and when the temperature permits of the regeneration of the roots. Indigo grown on porous soil in other parts of India under a high rainfall, such as Dehra Dun and the Chattisgarh Division of the Central Provinces, escapes wilt altogether. In Bihar, wilt is always most severe in years of heavy rainfall when the subsoil water remains at a high level for long periods. It is negligible in years of short rainfall like 1919 when the rise of the subsoil water is very slight.

Wilt in Bihar during the monsoon is by no means confined to Java indigo. It is common on many deep-rooted varieties of "patwa" (*Hibiscus cannabinus* L.) and "sann" (*Crotalaria juncea* L.) while shallow-rooted types of these two species are little affected. Further, surface-rooted species like "Roselle" (*Hibiscus Sabdariffa* L.) thrive no matter how wet the monsoon may be. The roots of Roselle in wet years exhibit marked aerotropism leaving the soil and growing all over the surface of the ground. The differences between the distribution of the roots of Roselle and of deep-rooted types of *patwa* are shown in Fig. 3, while in Fig. 4 the roots of an early and late type of *patwa* are illustrated. The surface-rooted Roselle crop and the early types of *patwa* do well at Pusa even if the soil becomes waterlogged occasionally. The deep-rooted types in such seasons, on the other hand, suffer severely from wilt. In such cases, the fine roots are destroyed from below upwards and the details follow closely those already described in the case of Java indigo.

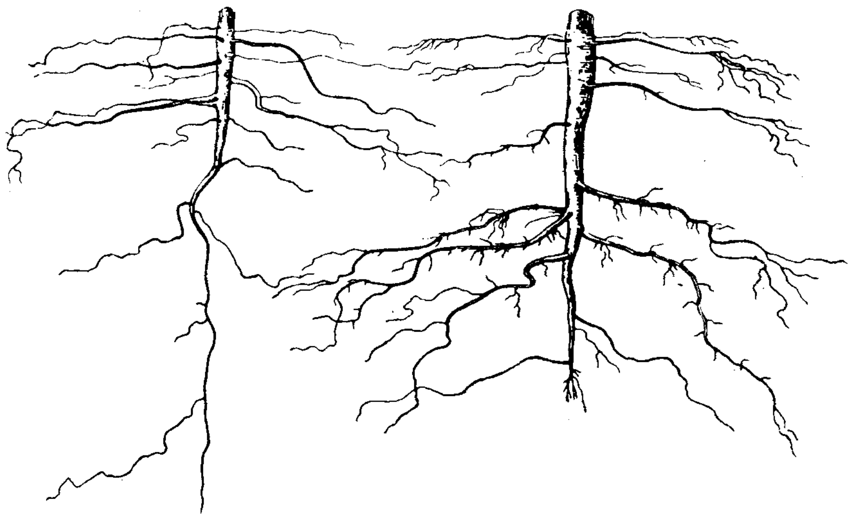

Fig. 4. Early (left) and late (right) types of root-systems in *H. cannabinus.*

Similar results have been obtained at Pusa in the case of two varieties of *sann* hemp (*Crotalaria juncea* L.). The local Bihar variety with surface roots sets seed but the deep-rooted tall variety from the black soils of the Central Provinces suffers from wilt and various insect diseases and hardly yields any seed crop.

The wilt diseases so far dealt with result from the slow destruction of the active root-system which follows the cessation of drainage and aeration during the rains. No parasite appears to be involved in any of these diseases. The remainder of this paper deals with diseases in which either insects or fungi are concerned, but in every case the actual attack follows the operation of some injurious factor such as poor soil-aeration, a high soil-temperature or increased humidity. All these cases require more detailed investigation which it is the object of this paper to provoke.

In connection with the investigation of the wilt disease of indigo and of *Hibiscus cannabinus*, some observations have been made on the conditions which appear to precede the attacks of two insects *Psylla isitis* Buckt. on indigo and the red cotton bug (*Dysdercus cingulatus* Fabr.) on *Hibiscus cannabinus*.

*Psylla* frequently attacks the stems and leaves of indigo leading to malformation and twisting of the growing points. Sometimes the attack stops at the end of the rains and the new leaves then become quite normal. Stems showing *Psylla* attack below and healthy foliage above are quite common and the attack does not spread to the new growth. It has been frequently observed at Pusa that applications of fresh undecayed organic matter (such as green manure) applied shortly before sowing as well as dressings of oil cake after sowing are always followed by severe attacks of *Psylla*. Examination of the root-system shows restricted and abnormal development and much discolouration of the active roots. The sequence of events is so well marked that the matter deserves to be studied in much greater detail. The fermentation of fresh organic matter in the soil seems to lead to changes in the sap and in the cells of the leaf which predispose the indigo plant to attack. In all cases we have examined, root discolouration precedes and accompanies the insect attack.

Equally interesting are the attacks by the red cotton bug on *Hibiscus cannabinus* at Pusa. These always follow the destruction of the fine roots and the onset of wilt. Year after year *patwa* grows normally during the early rains but when the wilt appears in September and October the plants attract swarms of the red bug. The wilt-free plots of Roselle in the neighbourhood are not attacked. Here again we appear to be confronted with a change in the cell-sap arising from root damage which prepares the way for the parasite.

*The rusts of wheat and linseed.* During the progress of the wheat experiments at Pusa, many hundreds of pure lines have been grown and in many cases the same cultures have been repeated year after year. In some instances, these pure lines have been grown in the field and also in flower-pots. In others, they have been grown immediately after the rains with or without a deep cultivation before sowing. Interesting differences between the amount of damage done by black rust (*Puccinia graminis* Pers.) to the same unit species in the same year have often been observed according to the way the plants were grown. In all cases, the individuals grown in flower-pots showed much less rust than the same unit species grown in the field and the difference was most marked. In flower-pots the roots of the wheat plants obtain a copious supply of air. This apparently increases the resistance of the plant, the rust colonies remain small and few in number and ripening of the grain takes place normally. When grown in the field, the aeration of the roots is reduced, the rust runs much more rapidly and the grain is often shrivelled. Similar differences in rust resistance are observed between plots of the same unit species when grown on heavy land with or without deep cultivation after the rains before sowing. The better the physical condition of the subsoil, the greater the rust resistance. This matter is being followed up further and the connection between rust attacks and the distribution and character of the root-system is being investigated at Pusa. Some interesting facts have already emerged. Several of the most rust-resistant wheats at Pusa are very shallow-rooted, some of the most rust-liable types from the black soils are exceedingly deep-rooted. Soil-aeration appears therefore to play an important part in the relations between the host and the parasite in rust attacks.

In the case of the linseed crop, the matter is being carried further. A large collection of the linseeds of India has been made at Pusa and the various unit species have been isolated and classified. The unit species fall into three groups according to the size of the seed and the character of the root-system. The linseeds of the black soils of Central India possess large seeds and a deep root-system which enables the crop to withstand the cracking of these soils. The types found in the plains have small seeds and a shallow root-system (Fig. 5). The third group is intermediate in all respects. When grown at Pusa in alluvial soil there is a great difference in the appearance of these groups of linseed. The small-seeded class is very luxuriant and does not suffer from rust and other diseases. The large-seeded deep-rooted class grows and sets seeds with difficulty. The plants appear starved and are often attacked by rust (*Melampsora Lini* Desm.). There is a very great difference in the appearance of the active roots of the deep-rooted types of linseed attacked by rust and the shallow-rooted types which escape this disease. The former appear starved and there is extensive discolouration. The latter are turgid, white and exceedingly vigorous.

*Red rot of sugar-cane.* One of the difficulties in sugar-cane cultivation on the black soil areas of the eastern tracts of the Central Provinces is the prevalence of red rot (*Colletotrichum falcatum* Went.), which, as is well-known, attacks the cane during the ripening period and leads to a great loss of sugar. This disease is also important in other parts of India, such as North Bihar, the Godavery delta in Madras, where soil-aeration difficulties are common. Some interesting results have been obtained by Clouston[1] in the Central Provinces on the effect of the physical texture of the soil on the resistance of the sugar-cane to this fungus. On the stiff black soils, in this track, red rot is common; on the neighbouring open porous *bhata* soils, however, crops as high as 40 tons of stripped cane to the acre are grown and there is a remarkable absence

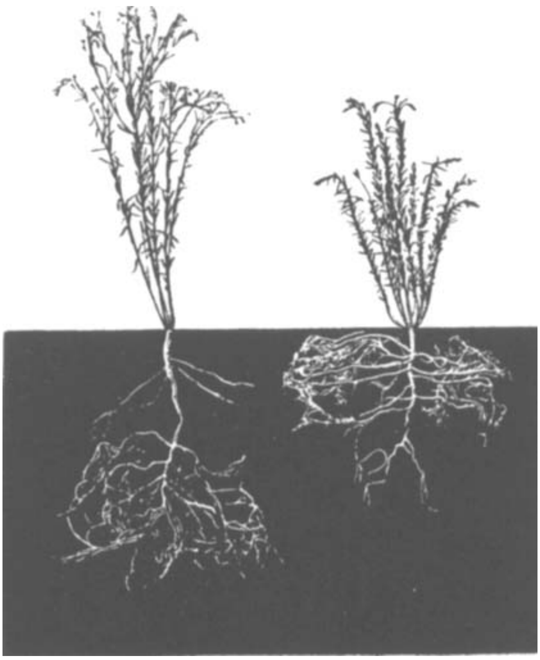

Fig. 5. Linseed from Central India (left) and the Indo-Gangetic alluvium (right).

of the red rot fungus. There appears to be here a case well worthy of more detailed investigation. Soil-aeration and healthy root-development confer a high degree of immunity on the sugar-cane, while the poor physical texture of the black soils appears to render this crop exceedingly susceptible to red rot. The sugar-cane readily lends itself to the investigation of its root-system and of its juices, as the plant is large and abundant material for research is readily available at many centres.

*The protection of fruit trees from green-fly.* The usual method of con-

[1] *Agr. Journ. of India*, Special Indian Science Congress Number, 1918, p. 89.

trolling attacks of green-fly is to spray the trees with some wash in which soft soap is one of the chief constituents. In practice, however, this procedure is of limited value as the affected trees soon become re-infected and the process has to be repeated, an important matter now that labour is becoming so expensive. It is generally considered that the only cause of green-fly attacks is the insect itself. If this is so, there seems no reason why the pest should not spread rapidly in any garden after its first appearance in the spring. This was not the case in the Quetta fruit experiment station, where this pest has been under observation for some years. Frequently trees remained quite free from green-fly in the immediate neighbourhood of others badly affected, and this has happened year after year. It would appear, therefore, that something else besides the green-fly is necessary for successful infection to take place.

Some light has been thrown on the conditions necessary for green-fly attacks as the result of a number of irrigation experiments at Quetta. Following American experience on certain soils, an attempt was made to store up water in the subsoil during the winter and spring for use during the subsequent hot weather, when water is very scarce. The experiments were successful as far as the saving of summer watering was concerned but the system had to be given up on account of the rapid increase in green-fly attacks which accompanied the winter irrigation. After the summer, only one watering is now given in October so as to ensure a sufficient supply of moisture in the soil to prevent the freezing of the roots by early frosts before the winter rains begin. The cessation of winter watering has at once been followed by the recovery of the trees from green-fly attack.

Among the experiments which have been conducted on this subject, the following may be quoted:

1. Four heavy winter irrigations were applied to three plots of peaches and one of nectarines during the winter of 1915–16. In all cases, the trees were very badly attacked by green-fly during April, 1916, and the attack was much more severe than in the neighbouring gardens. Further watering was then stopped and the soil round the trees was broken up down to the upper roots. In this way aeration was restored, and after about a month the new growth produced was free from *Aphides*. The trees then presented a remarkable appearance. The first-formed leaves on each twig showed extensive damage by *Aphides*, the late formed leaves on the same branch were normal and perfectly healthy.

2. The above four plots were treated in quite a different manner during the winter of 1916–17. After the summer, only one watering

was given—on Sept. 30th—and during the winter and spring no irrigation water at all was applied. As a result these plots were practically free from green-fly, the trees grew vigorously and the foliage showed all the characteristic appearances of healthy peach trees. These plots stood out in marked contrast to many of the trees to be seen in the Civil Station when in 1917 the ravages of green-fly were far above the average.

3. Three lines of almonds (a deep-rooted tree), and a plot composed largely of various stocks including plums, almonds and peaches, which were clean cultivated in 1916 and which were remarkably healthy and quite free from green-fly, were sown with shaftal (*Trifolium resupinatum*) right up to the stems in August and September, 1916. Several waterings were applied to these trees during the winter and spring. All the almonds, the seedling peaches, and some of the plum stocks became badly affected by green-fly soon after the leaves appeared at the end of March, 1917. By May, the attack was severe and practically all the young growth was affected. In this case, trees free from green-fly in 1916 lost in a single season all their immunity as a result of winter watering.

4. A number of almond and peach trees—grown under a system of furrow irrigation by which over-watering is almost impossible—were planted in the autumn of 1916 close to one of the lines of almonds which was over-watered during the winter. The object of this was to obtain another demonstration of the fact that insects like *Aphides* are unable to attack healthy plants. The over-watered trees were all affected by green-fly which in no case spread to the plants which had been watered by furrows and which had obtained an abundant supply of air for their roots.

These results, which have been repeated on several occasions at Quetta, suggest that the control of green-fly must be sought elsewhere than in the destruction of the insect. Soil-texture and soil-aeration in Baluchistan are markedly improved by a winter fallow and are known to suffer from over-watering during the cold season. This appears to affect the development of the roots of fruit trees in the spring by interfering with soil-aeration. A change in the sap seems to result after which the trees become attacked by green-fly. The connection between winter irrigation and green-fly has been obtained so frequently and is so definite that more detailed investigations of the soil, of the root-system and of the sap of the trees affected by green-fly is urgently called for. If, as appears possible, it is found that the insect can only attack trees in an abnormal condition, the prospects of the efficient control of this pest becomes much more hopeful.

## III. SOIL-TEMPERATURE.

Although soil-temperature is such an important factor in the distribution of the crops of India, both as regards season and the areas in which they occur, nevertheless but little attention has been paid to this growth factor in considering the incidence of disease. In India, the higher limit of temperature most frequently affects growth and in studying the crops of cold countries like wheat, which can only just be grown in India, this is one of the factors which frequently deserves attention.

*White ants and wheat seedlings.* One of the difficulties in wheat cultivation in Bihar and the eastern districts of the United Provinces is to establish the crop. If sown a few days too early, the seed germinates but the seedlings are rapidly destroyed by *Termites*, whole fields disappearing in a few days. The trouble became of some importance a few years ago in Bihar as it interfered with the raising of seed of the new Pusa wheats on some of the private seed farms[1]. The disease was particularly serious in years when the rains ceased early and when the last monsoon showers of early October, known locally as the *Lathia*, were not received. In such seasons, the advent of the cold weather is always postponed and the cool westerly breezes which normally set in about the middle of October are delayed till nearly the end of the month. The sowing time for wheat in Bihar in years when there is a good *Lathia* is just after the middle of the month and no trouble with white ants need then be feared. When, however, these sowing rains fail, nearly all the fields are destroyed by *Termites*. More damage occurs on low-lying damp heavy soil than on the higher and dryer areas. Examination of the root-system during the attack shows extensive discolouration of the new primary roots and of the first internode. Only in rare cases is there any formation of the secondary system. Before tillering can take place, the first internode is devoured by the white ants and the plants wither. A possible explanation of the trouble appeared to be a high soil-temperature which subsequent investigation seemed to confirm. In several seasons when the late rains failed, a comparison was made between sowings on Oct. 15th and others twelve days later. In addition to the delay, the furrows in the second case were left open for two or three days so as to cool the soil by evaporation. The early sowings were in every case destroyed by *Termites*, while in the later ones the damage was negligible and normal root-development and growth took place.

[1] *Agr. Journ. of India*, XI, p. 351.

The simplest explanation of these results appeared to be a fall in the soil-temperature during the second half of October. That such a fall actually does take place is proved by an examination of a set of soil-temperature determinations made by Leake at Pemberandah in Bihar in 1903–4. In the year in which Leake's readings were taken, the *Lathia* amounted to 3·4 inches of rain and the daily soil-temperature at 4 inches at 1–2 p.m., fell gradually from 29·5° C. on Oct. 16th to 22° C. at the end of the month. This disease of wheat seedlings, which is very common in north-east India, is of some general interest, as the *Termites*, although the apparent cause of the trouble, were in reality engaged in the consumption of a moribund set of seedlings which had been practically destroyed, apparently by a soil-temperature above the maximum for growth. Examination of the root-system in this case provided the clue which soon led to the discovery of the cause of the trouble and to the working out of a simple remedy, which has since been widely adopted on the indigo estates of this tract.

*The rust-resistance of einkorn*[1]. Einkorn (*Tritrium monococcum vulgare* Kche.) is well known to be exceedingly resistant to the attacks of black rust (*Puccinea graminis* Pers.). In 1907, a plot of this wheat was grown at Pusa when it was found to be immune to all the three species of rust which occur in north-east India. The plants however were still in the vegetative condition at harvest time and were allowed to grow during the hot weather to see if any ears would form. No change of this kind took place but early in May they were found to be severely attacked by black rust. Here a prolonged rise of temperature led to the complete loss of disease-resistance in a species considered to be immune to this fungus. Unfortunately, the root-system at the time of the attack was not examined, as the observations were made some years before any attention was paid to such matters at Pusa.

The various diseases referred to in this paper are considered to establish a case for the detailed investigation of the root-systems of plants, combined with a consideration of the chief soil factors, in connection with the study of disease. There seems to be no doubt that the conditions of the active roots profoundly affects the resistance of the plant to the attacks of parasites. What this actually means in the processes of metabolism is a matter for further investigation. The discolouration and damage to the absorbing areas of the root are not unlikely to lead to the entry of substances into the crude sap which

[1] *Journ. of Agr. Science*, II, p. 278.

may entirely alter its value to the plant. This in turn would influence the cell-sap throughout the shoot-system. How such alterations affect the struggle between the protoplasm, on the one hand, and the hyphae of an invading fungus on the other and why insects like *Aphides* thrive on the juices of a Quetta almond tree grown in soil consolidated by over-irrigation the previous winter and disregard it altogether under a different system of soil management are interesting problems for the vegetable pathologist eager to break new ground and to carry his science beyond the beaten track.

The examples quoted suggest another direction in which a knowledge of the root-system is desirable, namely, in the determination of the factors on which the disease-resistance of a unit species depends. A collection of unit species grown under any particular set of soil conditions generally exhibit among themselves marked differences in disease-resistance. At Pusa, it has been found in several crops that an investigation of the root-system throws a considerable amount of light on this point. Both in the rains and in the cold weather, deep-rooted varieties yield less and are more liable to disease than shallow-rooted types. Soil-aeration and its consequences will probably be found to be an important factor in this case. Many more examples of disease-resistance in other parts of the world must, however, be examined before we can say how far immunity depends on morphological root-fitness for the environment and how far it is inherent in the natural resistance of the protoplasm to the invasion of a parasite.